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Department of Energy
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Memorandum

MAY 1994
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ER:BKT:05261

Preliminary Remediation Goals

Susan Stiger, Associate General Manager
Environmental Restoration Management
EG&G Rocky Flats, Inc.



000028269

Hollowell

This memorandum is a follow-up to DOE/RFFO memorandum ER:SRG:03780, dated April 1, 1994, and is in response to EG&G memoranda SGS-164-194 and SGS-245-94 dated March 8 and April 15, 1994, respectively. In addition, meetings and a teleconference were held between our staffs on April 22 and 26, 1994, respectively.

The importance of Preliminary Remediation Goals (PRG) development to the Rocky Flats Plant (RFP) Environmental Restoration (ER) program needs to be recognized. Although the development of PRGs was precipitated by the Feasibility Study/Corrective Measures Study (FS/CMS) at Operable Unit (OU) 1, PRGs are critical path items for: (1) the chemical of concern (COC) selection process which uses risk-based concentrations (RBCs); (2) the CDH conservative screen which uses RBCs; (3) the FS/CMS's for all RFP OUs (especially OU 2); and (4) the ER Accelerated Cleanup program. The development of PRGs needs to be thorough and consistent in order to support these activities.

The development of PRGs contained in SGS-164-194 was deficient relative to overall RFP ER program requirements. The issues of greatest concern are: (1) the inconsistency of exposure scenarios and exposure pathways selected for PRGs relative to Baseline Risk Assessment, Exposure Scenario, Technical Memoranda for OUs 1 through 7 formally transmitted to the U. S. Environmental Protection Agency, Region VIII, (EPA) and the Colorado Department of Health (CDH); and (2) the use of overly conservative site-specific exposure factors.

The inconsistency of PRGs relative to OU technical memoranda was discussed in detail on April 22 and 26, 1994. These inconsistencies have been captured in the attachment (prepared by EG&G) which identifies requirements for additional environmental media, exposure scenarios and exposure pathways needed for PRG development. Failure to incorporate these scenarios and pathways in the PRG development process resulted from an inappropriate interpretation of EPA's "Risk Assessment Guidance for Superfund: Volume 1 - Human Health Evaluation Manual (Part B, Development of Risk-based Preliminary Remediation Goals)," dated December, 1991. Exhibit 2-1 in this document identifies default exposure scenarios and pathways. However, these default scenarios and pathways are inconsistent with those included in our Baseline Risk Assessments and Technical Memoranda.

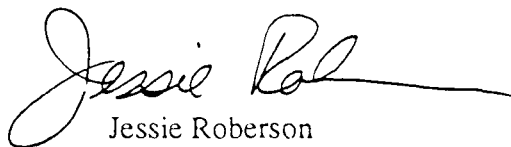
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Please note the following changes made to the attachment: (1) deletion of dermal exposure for soil and water; and, (2) addition of inhalation of volatiles (construction worker scenario). The deletion of dermal exposure is consistent with EG&G's initial recommendations to DOE/RFFO. Inspection of EPA's PRG guidance document referenced above along with EPA's "Dermal Exposure Assessment: Principles and Applications," dated January, 1992, indicate that a graded approach is appropriate for dermal exposure. Section 9 of the latter document contains the recommended process for evaluating dermal exposure in the Baseline Risk Assessment, while the former document indicates when dermal contact is to be considered for PRG development. We request that the decision to generate PRGs for dermal exposure be made by EG&G on a case-by-case basis for each OU based on the results of the Baseline Risk Assessment. With regard to inhalation of volatiles, pages 26, 27 and 29 of the PRG guidance indicate that soil to air volatilization (not groundwater to air) needs to be included in the construction worker scenario. We request that this pathway be included in the programmatic PRG development for the construction worker scenario.

We request that EG&G revise the PRGs such that: (1) consistency is achieved with this memorandum; (2) consistency is achieved with Baseline Risk Assessments and technical memoranda, and (3) the needs of all ER activities are satisfied. Since the OU 2 FS/CMS has the greatest short-term need for PRG development, we request that EG&G's PRG revision be prioritized such that PRGs associated with COCs for OU 2 are developed first. These should be provided to DOE/RFFO in a separate deliverable by May 30, 1994. The remaining PRGs should be submitted to DOE/RFFO by June 20, 1994.

The development of PRGs should include site-specific exposure factors discussed in DOE/RFFO memorandum ER:BKT:05262. Not only should risk assessments at the RFP be as realistic as possible, but PRGs should also be as realistic as possible. This will help to ensure that risk managers at DOE, EPA and CDH have the best information possible for making decisions.

Any questions or concerns should be addressed to Bruce Thatcher of my staff at extension 3532.


Jessie Roberson
Acting Assistant Manager for
Environmental Restoration

Attachment

cc w/Attachment:

F. Lockhart, ER, RFFO
S. Grace, ER, RFFO
R. Birk, ER, RFFO
J. Pepe, ER, RFFO
S. Slayton, ER, RFFO
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A. Howard, ESH, RFFO
J. Hopkins, EG&G
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A. Primrose, EG&G
T. O'Rourke, EG&G

PROGRAMMATIC PRELIMINARY REMEDIATION GOAL BASIS

TABLE 1

ENVIRONMENTAL MEDIA/ EXPOSURE SCENARIO	RESIDENTIAL	COMMERCIAL/ INDUSTRIAL		ECO-RESEARCHER
SURFACE SOIL, SHORELINE SEDIMENTS & STREAM SEDIMENTS	DIRECT INGESTION OF SOILS (a) INHALATION OF PARTICULATES (a) DERMAL CONTACT WITH SOILS (b) EXTERNAL RADIATION EXPOSURE (c)	OFFICE WORKER SCENARIO		DIRECT INGESTION OF SOILS (a) INHALATION OF PARTICULATES (a) DERMAL CONTACT WITH SOILS (b) EXTERNAL RADIATION EXPOSURE (c)
		DIRECT INGESTION OF SOILS (a) INHALATION OF PARTICULATES (a) DERMAL CONTACT WITH SOILS (b) EXTERNAL RADIATION EXPOSURE (c)		
		CONSTRUCTION WORKER SCENARIO		
SUBSURFACE SOIL	NOT APPLICABLE	DIRECT INGESTION OF SOILS (d) INHALATION OF PARTICULATES (d) DERMAL CONTACT WITH SOILS (b) EXTERNAL RADIATION EXPOSURE (c) <i>inhalation of volatiles</i>		NOT APPLICABLE
GROUND WATER (GW)	DIRECT INGESTION OF GW (d) INHALATION DURING DOMESTIC USE (e) DERMAL ABSORPTION DURING BATHING (f)	NOT APPLICABLE		NOT APPLICABLE
SURFACE WATER	DIRECT INGESTION WHILE SWIMMING (d)	NOT APPLICABLE		DIRECT INGESTION WHILE WADING (d)

- (a) - NON-VOLATILE ORGANICS AND INORGANICS WILL BE ASSESSED
(b) - NON-VOLATILE ORGANICS AND TRITIUM WILL BE ASSESSED
(c) - RADIONUCLIDES WILL BE ASSESSED
(d) - ORGANICS AND INORGANICS WILL BE ASSESSED
(e) - VOLATILE ORGANICS WILL BE ASSESSED
(f) - ORGANICS AND TRITIUM WILL BE ASSESSED

Co. <u>Region 9</u>	Co.
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REVISIONS TO CHAPTER 4
RISK-BASED PRGs FOR RADIOACTIVE CONTAMINANTS

- (1) Change in the Default Value for T_e Under the Commercial/Industrial Soil Scenario. The default value for the gamma exposure time factor, T_e , for workers, discussed in Section 4.1.2 and used in Equation (13) under the commercial/industrial soil exposure scenario, has been changed from 1 to 0.3. T_e is the ratio of the number of hours an individual is exposed to an external gamma radiation source during a 24-hr day. For workers, the exposure time is assumed to be 3 hours each day, resulting in a T_e value of 0.3 (i.e., 3/24). For residential populations, the exposure time is assumed to be 24 hours per day, with $T_e = 24/24 = 1$. Note that the default value for T_e for the residential soil scenario has not been changed.
- (2) Revision of the Default Values for SF_i for Ra-226/Rn-222 and Ra-224/Rn-220. (See Exhibit 3 attached.) The inhalation slope factor values listed for Rn-222 + D and Rn-220 + D in the box on page 40 have been replaced with the most current values taken from HEAST 1992 Table 4a. In addition, the discussions in the footnotes have been rewritten to provide better clarity.
- (3) Revision of Equations (11) and (11'). (See Exhibit 1 attached.) Equation (11) on page 37, which is used to calculate the risk-based radionuclide soil concentration, RS , for residential soils, has been revised to accept the new external exposure slope factors given in Table 4a of HEAST 1992. The "old" external slope factors were calculated assuming that individual gamma-emitting radionuclides were uniformly distributed over an infinite surface area with no depth, and were expressed in units of risk/year per pCi/m² of soil. In the original Equation (11), assumptions had to be made for the depth of radionuclides in soil, D , and the soil density, SD . Since the "new" external exposure slope factors account for soil depth and density (and are expressed in correct units of risk/year per pCi/g soil), the terms D and SD have been dropped from the revised Equation (11). Revised Equation (11') in Exhibit 1 is the reduced form of revised Equation (11).
- (4) Revision of Equations (13) and (13') and Addition of Equation (13''). (See Exhibit 2 attached.) Similar to the revision of Equation (11) discussed above, Equation (13) on page 39, has also been revised to accept the new external exposure slope factors in Table 4a of HEAST 1992. The terms D and SD have been dropped from the revised Equation (13). Revised Equation (13') in Exhibit 2 - for use in calculations involving volatile radionuclides - is the reduced form of revised Equation (13). Reduced Equation (13'') has been added for use in calculations involving non-volatile radionuclides, and differs from Equation (13') by dropping the soil-to-gas volatilization factor (VF) from the calculations.

RADIONUCLIDE PRG: RESIDENTIAL SOIL — CARCINOGENIC EFFECTS

$$\text{Total risk} = \text{RS} \times ((\text{SF}_i \times 10^{-3}/\text{mg} \times \text{EF} \times \text{IF}_{\text{soil}}) + (\text{SF}_e \times \text{ED} \times (1-3) \times \text{T}))$$

$$\text{RS (pCi/g; risk-based)} = \frac{\text{TR}}{(\text{SF}_i \times 10^{-3}/\text{mg} \times \text{EF} \times \text{IF}_{\text{soil}}) + (\text{SF}_e \times \text{ED} \times (1-3) \times \text{T})} \quad (11)$$

where:

Parameters	Definition (units)	Default Value
RS	radionuclide PRG in soil (pCi/g)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF_i	oral (ingestion) slope factor (risk/pCi)	radionuclide-specific
SF_e	external exposure slope factor (risk/yr per pCi/g)	radionuclide-specific
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
IF_{soil}	age-adjusted soil ingestion factor (mg-yr/day)	3600 mg-yr/day (see Equation (12))
S	gamma shielding factor (unitless)	0.2 (see Section 4.1.2)
T	gamma exposure time factor (unitless)	1 (see Section 4.1.2)

REDUCED EQUATION FOR RADIONUCLIDE PRG:
RESIDENTIAL SOIL — CARCINOGENIC EFFECTS

$$\text{Risk-based PRG (pCi/g; TR} = 10^{-6}) = \frac{1 \times 10^{-6}}{1.3 \times 10^3 (\text{SF}_i) + 24(\text{SF}_e)} \quad (11')$$

where:

SF_i	= radionuclide-specific oral (ingestion) slope factor (risk/pCi)
SF_e	= radionuclide-specific external exposure slope factor (risk/yr per pCi/g)

Exhibit 2. Revised Equations for Calculating Radionuclide PRGs — Commercial/Industrial Soil

RADIONUCLIDE PRGs: COMMERCIAL/INDUSTRIAL SOIL — CARCINOGENIC EFFECTS*

$$\text{Total risk} = \text{RS} \times \text{ED} \times \left((\text{SF}_i \times 10^3 \text{ g/mg} \times \text{EF} \times \frac{\text{TR}}{\text{TR}}) + (\text{SF}_e \times 10^3 \text{ g/kg} \times \text{EF} \times \text{ED} \times \text{LVEF}) \right. \\ \left. + (\text{SF}_v \times 10^3 \text{ g/kg} \times \text{EF} \times \text{ED} \times \text{LVEF}) + (\text{SF}_i \times (1-\text{S}) \times \text{TD}) \right)$$

$$\text{RS (pCi/g)} = \frac{\text{TR}}{\text{ED} \times \left((\text{SF}_i \times 10^3 \text{ g/mg} \times \text{EF} \times \frac{\text{TR}}{\text{TR}}) + (\text{SF}_e \times 10^3 \text{ g/kg} \times \text{EF} \times \text{ED} \times (\text{LVEF} + \text{LVEF})) + (\text{SF}_i \times (1-\text{S}) \times \text{TD}) \right)}$$

where:

Parameter	Definition (units)	Default Value
RS	radionuclide PRG in soil (pCi/g)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF _i	oral (ingestion) slope factor (risk/pCi)	radionuclide-specific
SF _e	external exposure slope factor (risk/yr per pCi/g)	radionuclide-specific
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	25 yr
R _i	workday inhalation rate of air (m ³ /day)	20 m ³ /day
R _{so}	daily soil ingestion rate (mg/day)	50 mg/day
VF	soil-to-air volatilization factor (m ³ /kg)	radionuclide-specific (see Section 4.2.3)
ppm	particulate emission factor (m ³ /kg)	4.63×10^3 m ³ /kg (see Section 3.3.2)
S _g	gamma shielding factor (unitless)	0.2 (see Section 4.1.2)
T _g	gamma exposure time factor (unitless)	0.3 (see Section 4.1.2)

SF_i in inhalation
NOTE: Most radionuclides are not volatile under normal ambient conditions. For these radionuclides, the soil-to-air volatilization exposure pathway may be omitted from risk-based calculations (see Section 4.2.3).

REDUCED EQUATION FOR RADIONUCLIDE PRGs: COMMERCIAL/INDUSTRIAL SOIL — CARCINOGENIC EFFECTS*

(a) Reduced equation for volatile radionuclides:

$$\text{Risk-based PRG} = \frac{1 \times 10^{-6}}{3.1 \times 10^4 (\text{SF}_i) + (1.3 \times 10^4 \text{ VF} + 2.7 \times 10^4 (\text{S}_g^2) + 6 (\text{S}_g))} \quad (13')$$

(b) Reduced equation for non-volatile radionuclides:

$$\text{Risk-based PRG} = \frac{1 \times 10^{-6}}{3.1 \times 10^4 (\text{SF}_i) + 2.7 \times 10^4 (\text{S}_g^2) + 6 (\text{S}_g)} \quad (13'')$$

where:

SF _i	= radionuclide-specific oral (ingestion) slope factor (risk/pCi)
SF _e	= radionuclide-specific external slope factor (risk/pCi)
SF _v	= radionuclide-specific external exposure slope factor (risk/yr per pCi/g)
VF	= radionuclide-specific soil-to-air volatilization factor (m ³ /kg) (see Section 4.2.3)

* NOTE: See Section 4.2.3 when calculating PRGs for Ra-226/Rn-222 and Ra-224/Rn-220.

Exhibit 3. Revised Soil Default Values for SF_i for
Ra-226/Rn-222 and Ra-224/Rn-220

Soil Default Values for VF and SF_i
for Ra-226/Rn-222 and Ra-224/Rn-220

Radium	Default VF Value [*] (pCi/kg Ra per pCi/m ³ Rn)	Inhalation Slope Factor, SF _i (m ³ /kg·d) ^{**}
Ra-226	8	7.7E-12
Ra-224	200	5.0E-11

* The default VF value of 8 for Ra-226 was calculated as the ratio of the average natural background concentration of Ra-226 in soil (1,000 pCi/kg) to the corresponding average natural background concentration of Rn-222 in air (120 pCi/m³). Similarly, the default VF value of 200 for Ra-224 was calculated as the ratio of the average Ra-224 background concentration in soil (1,000 pCi/g) to the average Rn-220 background concentration in air (5 pCi/m³). Natural background levels for radium and radon were taken from NCRP 1976 and UNSCEAR 1982.

** Inhalation slope factor values are for Ra-222 plus decay products (i.e., Ra-222 + D) formed from the radioactive decay of Ra-226, and for Ra-220 + D from the decay of Ra-224. SF values were taken from Table 4a of EPA's Health Effects Assessment Summary Tables (HEAST 1992).

NOV 9 1992

NOTE TO: Regional Toxic Integration Coordinators
FROM: Janine Dinan *Janine Dinan*
SUBJECT: Changes to Equations in the Part B Guidance

Attached are updates to the soil-to-air volatilization and radiation equations presented in the Risk Assessment Guidance for Superfund, Human Health Evaluation Manual: Part B (December, 1991).

OERR asked the Air/Superfund contractor (Environmental Quality Management) to perform a limited validation study on the volatilization factor (VF) equation presented in Part B. As a result of that study, they felt it would be better to modify the equation to take into account the effect of soil moisture on the flux of chemicals through the soil. The original Hwang and Falco model used in Part B did not take in account the effect of soil moisture. The validation study showed, that for some of the more volatile and soluble compounds (Benzene, Toluene, Ethylbenzene and Xylenes), the Part B equation over-predicted emissions by a factor of 5 to 10. In addition, EQM suggested that we modify the soil saturation concentration (C_{ms}) equation to reflect the fraction of a chemical found in the vapor phase as well the fractions bound to the organic content of soil and dissolved in the soil moisture.

Since Part B was developed, the Office of Radiation Programs has changed the way it calculates slope factors for external exposures. As a result the units are different than the ones originally presented in Part B. To avoid confusion, we felt it was best to develop modified equations.

Although a more formal memo will be distributed to the Regions (and other users of Part B) with this information, I felt that you should have these changes in hand as soon as possible.

OPTIONAL FORM 90 (7-90)

FAX TRANSMITTAL		# of pages > 8
To: <i>Jennifer Wheeler</i>	From: <i>Seamon Ballard</i>	
Dept./Agency: <i>Clement</i>	Phone: <i>404 347-7109</i>	
Fax: <i>(403) 934-9242</i>	Fax: <i></i>	

PSN 7530-31-317-7388 5010-101 GENERAL SERVICES ADMINISTRATION

Soil-to-Air Volatilization Factor (VF)

The volatilization factor (VF) is used for defining the relationship between the concentration of contaminant in soil and the volatilized contaminant in air. This relationship was established as part of the Hwang and Falco (1986) model developed by EPA's Exposure Assessment Group in the Office of Research and Development. Hwang and Falco present a method intended primarily to estimate the permissible residual levels associated with the cleanup of contaminated soils.

The Hwang and Falco model was used as the basis for the VF equation presented in the Part B guidance. Since the time of Part B, OERR sponsored a study to validate the VF equation by comparing the modelled results with data from actual bench and pilot scale studies. The results of the validation study (EQM, 1992) suggested the need to modify the VF equation in Part B to take into account the decrease in the rate of flux due to the effect of soil moisture on effective diffusivity (D_e). Thus, the D_e equation for dry soil ($D_e \propto P_a^{1/3}$) was replaced with an equation from Millington and Quirk (1961) where $D_e = D_i (P_a^{1/3}/P_t^{1/3})$.

$$VF \text{ (m}^3/\text{kg)} = \frac{(LS \times V \times DH)}{A} \times \frac{(3.14 \times \alpha \times T)^{1/2}}{(2 \times D_{e,i} \times P_a \times K_{a,i} \times 10^{-3} \text{ kg/mg})}$$

where:

$$\alpha = \frac{D_{e,i} \times P_a}{P_a + (\rho_s) (1 - P_a) / K_{a,i}}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
VF	Volatilization factor (m ³ /kg)	--
LS	Length of side of contaminated area (m)	45
V	Windspeed in mixing zone (m/s)	2.25
DH	Diffusion height (m)	2
A	Area of contamination (cm ²)	20,250,000
$D_{e,i}$	Effective diffusivity (cm ² /s)	$D_i (P_a^{1/3}/P_t^{1/3})$
P_a	Air filled soil porosity (unitless)	$P_t - \theta \beta$
P_t	Total soil porosity (unitless)	$1 - (\beta/\rho_s)$

θ	Soil moisture content (cm ³ -water/g-soil)	10% or 0.1
ρ	Soil bulk density (g/cm ³)	1.5
ρ_p	True soil density or particle density (g/cm ³)	2.65
K_{oa}	Soil-air partition coefficient (g-soil/cm ³ -air)	(H/K _o) x 41 (41 is a conversion factor)
T	Exposure interval (s)	7.9 x 10 ⁴ s
D _i	Diffusivity in air (cm ² /s)	Chemical- specific
H	Henry's Law constant (atm-m ³ /mol)	Chemical- specific
K _o	Soil-water partition coefficient (cm ³ /kg)	K _{ow} x OC
K _{ow}	Organic carbon partition coefficient (cm ³ /kg)	Chemical- specific
OC	Organic carbon content of soil (fraction)	2% or 0.02

Soil Saturation Concentration (C_{sat})

The basic principle of the VF model is applicable only if the soil contaminant concentration is at or below saturation. Saturation is the soil contaminant concentration at which the adsorptive limits of the soil particles and the solubility limits of the available soil moisture have been reached. Above saturation, pure liquid-phase contaminant is expected in the soil. Under such conditions, the partial pressure of the pure contaminant and the partial pressure of the air in the interstitial pore spaces cannot be calculated without first knowing the mole fraction of the contaminant in the soil. Therefore, above saturation the PRG cannot be accurately calculated based on volatilization. Because of this limitation, the chemical concentration in soil (PRG) calculated using VF must be compared with the soil saturation concentration (C_{sat}). If the PRG calculated using VF is greater than C_{sat}, the PRG should be set equal to C_{sat}.

REVISIONS TO CHAPTER 4
RISK-BASED PRGs FOR RADIOACTIVE CONTAMINANTS

- (1) **Change in the Default Value for T_e Under the Commercial/Industrial Soil Scenario.** The default value for the gamma exposure time factor, T_e , for workers, discussed in Section 4.1.2 and used in Equation (13) under the commercial/industrial soil exposure scenario, has been changed from 1 to 0.3. T_e is the ratio of the number of hours an individual is exposed to an external gamma radiation source during a 24-hr day. For workers, the exposure time is assumed to be 8 hours each day, resulting in a T_e value of 0.3 (i.e., 8/24). For residential populations, the exposure time is assumed to be 24 hours per day, with $T_e = 24/24 = 1$. Note that the default value for T_e for the residential soil scenario has not been changed.
- (2) **Revision of the Default Values for SF_i for Ra-226/Rn-222 and Ra-224/Rn-220.** [See Exhibit 3 attached.] The inhalation slope factor values listed for Rn-222+D and Rn-220+D in the box on page 40 have been replaced with the most current values taken from HEAST 1992 Table 4a. In addition, the discussions in the footnotes have been rewritten to provide better clarity.
- (3) **Revision of Equations (11) and (11').** [See Exhibit 1 attached.] Equation (11) on page 37, which is used to calculate the risk-based radionuclide soil concentration, RS , for residential soils, has been revised to accept the new external exposure slope factors given in Table 4a of HEAST 1992. The "old" external slope factors were calculated assuming that individual gamma-emitting radionuclides were uniformly distributed over an infinite surface area with no depth, and were expressed in units of risk/year per pCi/m² of soil. In the original Equation (11), assumptions had to be made for the depth of radionuclides in soil, D , and the soil density, SD . Since the "new" external exposure slope factors account for soil depth and density (and are expressed in correct units of risk/year per pCi/g soil), the terms D and SD have been dropped from the revised Equation (11). Revised Equation (11') in Exhibit 1 is the reduced form of revised Equation (11).
- (4) **Revision of Equations (13) and (13') and Addition of Equation (13'').** [See Exhibit 2 attached.] Similar to the revision of Equation (11) discussed above, Equation (13) on page 39, has also been revised to accept the new external exposure slope factors in Table 4a of HEAST 1992. The terms D and SD have been dropped from the revised Equation (13). Revised Equation (13') in Exhibit 2 - for use in calculations involving volatile radionuclides - is the reduced form of revised Equation (13). Reduced Equation (13'') has been added for use in calculations involving non-volatile radionuclides, and differs from Equation (13') by dropping the soil-to-gas volatilization factor (VF) from the calculations.

Exhibit 1. Revised Equations for Calculating Radionuclide PRGs — Residential Soil

RADIONUCLIDE PRG: RESIDENTIAL SOIL — CARCINOGENIC EFFECTS

$$\text{Total risk} = \text{RS} \times [(\text{SF}_o \times 10^{-6} \text{ g/mg} \times \text{EF} \times \text{IF}_{\text{soil}}) + (\text{SF}_e \times \text{ED} \times (1-S_\gamma) \times \text{T})]$$

$$\text{RS (pCi/g; risk-based)} = \frac{\text{TR}}{(\text{SF}_o \times 10^{-6} \text{ g/mg} \times \text{EF} \times \text{IF}_{\text{soil}}) + (\text{SF}_e \times \text{ED} \times (1-S_\gamma) \times \text{T})} \quad (11)$$

where:

Parameters	Definition (units)	Default Value
RS	radionuclide PRG in soil (pCi/g)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF _o	oral (ingestion) slope factor (risk/pCi)	radionuclide-specific
SF _e	external exposure slope factor (risk/yr per pCi/g)	radionuclide-specific
EF	exposure frequency (days/yr)	350 days/yr
ED	exposure duration (yr)	30 yr
IF _{soil}	age-adjusted soil ingestion factor (mg-yr/day)	3600 mg-yr/day (see Equation (12))
S _γ	gamma shielding factor (unitless)	0.2 (see Section 4.1.2)
T	gamma exposure time factor (unitless)	1 (see Section 4.1.2)

**REDUCED EQUATION FOR RADIONUCLIDE PRG:
RESIDENTIAL SOIL — CARCINOGENIC EFFECTS**

$$\text{Risk-based PRG (pCi/g; TR} = 10^{-6}) = \frac{1 \times 10^{-4}}{1.3 \times 10^3 (\text{SF}_o) + 24(\text{SF}_e)} \quad (11')$$

where:

SF _o	= radionuclide-specific oral (ingestion) slope factor (risk/pCi)
SF _e	= radionuclide-specific external exposure slope factor (risk/yr per pCi/g)

Exhibit 2. Revised Equations for Calculating Radionuclide PRGs — Commercial/Industrial Soil

RADIONUCLIDE PRGs: COMMERCIAL/INDUSTRIAL SOIL — CARCINOGENIC EFFECTS*

$$\text{Total risk} = \text{RS} \times \text{ED} \times [(\text{SF}_o \times 10^{-3} \text{ g/mg} \times \text{EF} \times \text{IR}_{\text{soil}}) + (\text{SF}_i \times 10^{-3} \text{ g/kg} \times \text{EF} \times \text{IR}_{\text{soil}} \times 1/\text{VF}) + (\text{SF}_i \times 10^{-3} \text{ g/kg} \times \text{EF} \times \text{IR}_{\text{soil}} \times 1/\text{PEF}) + (\text{SF}_g \times (1 - S_g) \times T)]$$

$$\text{RS (pCi/g; risk-based)} = \frac{\text{TR}}{\text{ED} \times [(\text{SF}_o \times 10^{-3} \text{ g/mg} \times \text{EF} \times \text{IR}_{\text{soil}}) + ((\text{SF}_i \times 10^{-3} \text{ g/kg} \times \text{EF} \times \text{IR}_{\text{soil}}) \times (1/\text{VF} + 1/\text{PEF})) + (\text{SF}_g \times (1 - S_g) \times T)]} \quad (13)$$

where:

Parameters	Definition (units)	Default Value
RS	radionuclide PRG in soil (pCi/g)	—
TR	target excess individual lifetime cancer risk (unitless)	10^{-6}
SF _o	oral (ingestion) slope factor (risk/pCi)	radionuclide-specific
SF _i	external exposure slope factor (risk/yr per pCi/g)	radionuclide-specific
EF	exposure frequency (days/yr)	250 days/yr
ED	exposure duration (yr)	25 yr
IR _{soil}	workday inhalation rate of air (m ³ /day)	20 m ³ /day
IR _{soil}	daily soil ingestion rate (mg/day)	50 mg/day
VF	soil-to-air volatilization factor (m ³ /kg)	radionuclide-specific (see Section 4.2.3)
PEF	particulate emission factor (m ³ /kg)	4.63×10^6 m ³ /kg (see Section 3.3.2)
S _g	gamma shielding factor (unitless)	0.1 (see Section 4.1.2)
T	gamma exposure time factor (unitless)	0.3 (see Section 4.1.2)

* NOTE: Most radionuclides are not volatile under normal ambient conditions. For these radionuclides, the soil-to-air volatilization exposure pathway may be omitted from risk-based calculations (see Section 4.2.3).

REDUCED EQUATION FOR RADIONUCLIDE PRGs: COMMERCIAL/INDUSTRIAL SOIL — CARCINOGENIC EFFECTS*

(a) Reduced equation for volatile radionuclides:

$$\text{Risk-based PRG (pCi/g; TR} = 10^{-6}) = \frac{1 \times 10^{-4}}{3.1 \times 10^3 (\text{SF}_o) + (1.3 \times 10^4 / \text{VF}) + 2.7 \times 10^3 (\text{SF}_i) + 6 (\text{SF}_g)} \quad (13')$$

(b) Reduced equation for non-volatile radionuclides:

$$\text{Risk-based PRG (pCi/g; TR} = 10^{-6}) = \frac{1 \times 10^{-4}}{3.1 \times 10^3 (\text{SF}_o) + 1.7 \times 10^4 (\text{SF}_i) + 6 (\text{SF}_g)} \quad (13'')$$

where:

SF _o	= radionuclide-specific oral (ingestion) slope factor (risk/pCi)
SF _i	= radionuclide-specific oral (ingestion) slope factor (risk/pCi)
SF _g	= radionuclide-specific external exposure slope factor (risk/yr per pCi/g)
VF	= radionuclide-specific soil-to-air volatilization factor (m ³ /kg) (see Section 4.2.3)

* NOTE: See Section 4.2.3 when calculating PRGs for Ra-226/Rn-222 and Ra-224/Rn-220.

Exhibit 3. Revised Soil Default Values for SF_i for
Ra-226/Rn-222 and Ra-224/Rn-220

Soil Default Values for VF and SF_i
for Ra-226/Rn-222 and Ra-224/Rn-220

Radium	Default VF Value* (pCi/kg Ra per pCi/m ³ Rn)	Inhalation Slope Factor, SF _i (risk/pCi)**
Ra-226	8	7.7E-12
Ra-224	200	5.0E-11

* The default VF value of 8 for Ra-226 was calculated as the ratio of the average natural background concentration of Ra-226 in soil (1,000 pCi/kg) to the corresponding average natural background concentration of Rn-222 in air (120 pCi/m³). Similarly, the default VF value of 200 for Ra-224 was calculated as the ratio of the average Ra-224 background concentration in soil (1,000 pCi/g) to the average Rn-220 background concentration in air (5 pCi/m³). Natural background levels for radium and radon were taken from NCRP 1976 and UNSCEAR 1982.

** Inhalation slope factor values are for Ra-222 plus decay products (i.e., Ra-222+D) formed from the radioactive decay of Ra-226, and for Ra-220+D from the decay of Ra-224. SF values were taken from Table 4a of EPA's Health Effects Assessment Summary Tables (HEAST 1992).

$$C_{\text{sat}} = \frac{(K_d \times C_v \times \beta) + (C_v \times P_v) + (C_v \times H' \times P_a)}{\beta}$$

<u>Parameter</u>	<u>Definition (units)</u>	<u>Default</u>
C_m	Soil saturation concentration (mg/kg)	--
K_d	Soil-water partition coefficient (L/kg)	$K_{oc} \times OC$
K_{oc}	Organic carbon partition coefficient (L/kg)	Chemical-specific
OC	Organic carbon content of soil (fraction)	2% or 0.02
C_v	Upper limit of free moisture in soil (mg/L-water)	$S \times \theta_m$
θ_m	Soil moisture content (kg-water/kg-soil)	10% or 0.1
S	Solubility in water (mg/L-water)	Chemical-specific
β	Soil bulk density (kg/L)	1.5
P_v	Water filled soil porosity (unitless)	$P_t - P_a$
H'	Henry's Law constant (unitless)	$H \times 41$, where 41 is a conversion factor
H	Henry's Law constant (atm-m ³ /mol)	Chemical-specific
P_a	Air-filled soil porosity (unitless)	$P_t - \theta\beta$
θ	Soil moisture content (L-water/kg soil)	10% or 0.1
P_t	Total soil porosity (unitless)	$1 - (\beta/\rho_s)$
ρ_s	True soil density or particle density (kg/L)	2.65

Please note that the equation presented here for C_m is also a modification of the equation presented in the Part B guidance. This equation also takes into account the amount of contaminant that is in vapor phase in the pore spaces of the soil.